DEVELOPMENT OF REPETITIVE CURRENT CONTROLLER USING RASPBERRY PI FOR 3 PHASE ACTIVE POWER FILTER FOR NONLINEAR LOAD IMPROVEMENT

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ABSTRACT

This project is about to design the repetitive controller to compensate the distorted current in the three phase power supply by using active power filter (APF). The APF used is three phase bridge inverter which converts DC to AC waveform. The inverter use Metal Oxide Semiconductor Field Effect Transistor (MOSFET). The Raspberry Pi board is used to supply the pulse width modulation (PWM) signal to the APF. Lastly, the repetitive controller is designed so that the PWM generated is the same signal to be compensated by the APF and enhanced distorted current in power supply into the pure AC waveform. In this project, all the ideas have been applied and tried physically and the output of this project is to get pure sinusoidal waveform at the three phase power supply.

ABSTRAK

Tujuan utama projek ini adalah untuk mereka suatu kaedah bagi mengimbangi arus yang terganggu dalam bekalan kuasa tiga fasa tersebut dengan menggunakan penapis kuasa aktif (APF). APF yang digunakan adalah jambatan penyogsang tiga fasa yang menukarkan gelombang arus terus ke gelombang arus ulang alik. Penyongsang tersebut menggunakan “Metal Oxide Semiconductor Field Effect Transistor” (MOSFET). Kemudian terdapat papan Rasberry Pi yang akan membekalkan isyarat nadi modulasi lebar (PWM) kepada pemacu get dan mengawal pensuisan MOSFET dalam penyongsang. Akhir sekali, pengawal berulang direka supaya PWM yang terhasil adalah isyarat sama yang akan diimbangi oleh penyongsang dan meningkatkan arus yang terganggu dalam bekalan kuasa kepada gelombang arus ulang alik yang asli. Dalam projek ini, semua idea telah diguna dan dicuba secara fizikal dan hasil daripada projek ini adalah untuk mendapatkan gelombang sinusoidal yang asli pada sumber kuasa tiga fasa.

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LIST OF SYMBOLS AND ABBREVIATIONS

APF	-	Active power filter
LPF	-	Low pass filter
PWM	-	Pulse width modulation
THD	-	Total harmonics distortion
MOSFET	-	Metal oxide semiconductor field effect transistor
IGBT	-	Insulator gate bipolar transistor
FFT	-	Fast fourier transform
PID	-	Proportional integral derivative
PCB	-	Printed circuit board
AC	-	Alternating current
DC	-	Direct current

CHAPTER 1

INTRODUCTION

The introduction chapter consists of research background, problem statement, research objectives, limitations or scope of study and lastly the outline of this project report.

1.0 Research Background

For this project, the nonlinear load will make the current distorted and unbalance [1] . A three phase APF is used to compensate the current for a nonlinear load into the supply line. The ability of the Raspberry Pi can be tested by trying to run an application of repetitive current controller. So the repetitive current controller is designed to compensate the nonlinear current. The controller will inject the pulse width modulator (PWM) to the APF and the APF will compensate the nonlinear current until it becomes pure sinusoidal waveform. The overall project is shown as in Figure 1.1.

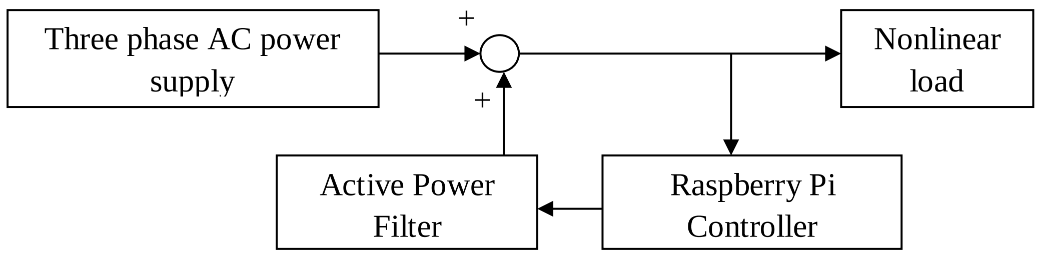

Figure 1.1: Block diagram of the project

Then, the Raspberry Pi board is needed to inject the digital signal to the APF as in Figure 1.1. Raspberry Pi board is a new technology which enables the user to run a program language into it such as Phyton, Scratch, Java, and C+/C++. In this project, the design of the repetitive current controller by using Simulink Matlab software will be downloaded into the Raspberry Pi board.

1.2 Problem Statement

The rectifier which is connected to the resistor will become the source of nonlinear load and as the result, harmonics current will occur [2]. Harmonics have many disadvantages to a system such as power loss where rising heat of the system as well as the system can be damaged [3]. This power loss will make the cost of running this system with nonlinear load likely become higher than usual [4]. In this modern day, the usage of three phase APF is widely used in industry because it can reduce power loss due to switching frequency [5]. But the design of APF cannot stand alone since it must have PWM to control the transistor in order to achieve the desired output. So, this project is mainly for designing the PWM of the APF by using repetitive current controller. Many have used traditional way of controlling such as low cost microcontroller. Even though the cost is cheaper, but the programming part is very tricky, because it has its own programming language. So, without powerful knowledge about programming the microcontroller, the project will become difficult to achieve. This project is important since there are not many people have used Raspberry Pi board as a controller in their project since it is just launched into the market. So there are limited paper researches about Raspberry Pi.

1.3 Research Objective

The aim of this project is to design the repetitive current controller for 3 phase APF for nonlinear load improvement. There are 3 main objectives to achieve this as proposed below:

(i) To design the repetitive current controller by using Matlab.
(ii) To integrate between Simulink in Matlab and Raspberry Pi controller.
(iii) To develop and testing the APF system.

1.4 Limitations / scope of the study

The limitations of the project have been set as below so that the area of project can be focused to achieve the objectives above. The scope of study proposed as below:

(i) Repetitive current controller will be used as the control application for APF mitigation.
(ii) The controller only compensate current for nonlinear load
(iii) The controller will be designed by using Simulink in Matlab
(iv) Raspberry Pi will be used as the signal generator to APF
(v) Only three phase APF will be used to compensate nonlinear current at load

1.5 Outline of the thesis

The first chapter is only the introduction of this thesis. The chapter covers the brief idea about the project that has to be done generally.

The second chapter will cover all the literature review about the project that has been done before. It will cover all the fundamental principles, commercial product and the previous work that has been researched on.

Chapter 3 will cover the methodology of this project. The methodology is on the works that must be done in order to achieve the objectives given before.

Chapter 4 covers the results acquired while doing the simulation by using Matlab. Other than that, the results after constructed the circuit physically must be done in this this chapter. Then the analysis will be done based on the results gained.

The last chapter will summarize all the works that has been done in this project. This chapter will summarize the problems faced during the project and the solution found to handle the problems occurred. Then several recommendations need to be proposed so the continuity on this research can be done later.

CHAPTER 2

LITERATURE REVIEW

This chapter will introduce the previous research or works done before about nonlinear load, 3 phase APF, as well as the controller used to compensate the current shortage in the nonlinear system. The research including the usage of Matlab and Raspberry Pi for testing and the results acquired. Other than that, this chapter will emphasize the importance of this project, and the differences between it with other works.

2.1 Nonlinear load

The first thing, the research has taken place for nonlinear load. The presence of nonlinear load will make the line current becomes harmonics, following the load [6][7][8]. The nonlinear load can come from the resistance inductance and capacitance (RLC) load. This RLC circuit will increase the total harmonics distortion in the current line and distorted. This nonlinearity will decrease the power factor by increasing the total harmonics distortion (THD)[3][9].

There is a paper which talked about voltage source nonlinear load and current source nonlinear load [9]. The nonlinear load comes from the rectifier and the resistor-capacitor or resistor inductor. The configuration in this proposal is rectifier with resistor and inductor connected in series as shown in Figure 2.1.

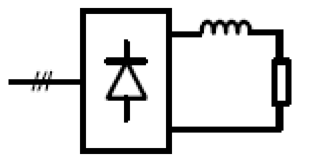

Figure 2.1: Model for nonlinear load [9]

2.2 3 phase active power filter

In this modern day, 3 phase APF has been widely used due to the upgrading system in electric and electronics applications. Many high end applications have been using 3 phase rectifiers such as arc welding, 3 phase ac induction motors are the nonlinear load that will contribute to the non-sinusoidal current. This non-sinusoidal current will generate harmonics in the system and the power quality of the system will reduce [5][10]. So, in order to reduce this harmonics, the 3 phase APF is used.

The configuration of simple 3 phase APF has been shown in Figure 2.2. The commonly used APF is by using three phase inverter. The inverter which converts the DC voltage to the AC voltage is useful to compensate the current distortion, depending on the PWM topologies for the gate driver. The whole concept of APF system works by injecting the pulse of harmonics into the nonlinear system. The harmonics will cancel out with the harmonics generated by the nonlinear system and as the result; the pure sinusoidal current will formed [5].

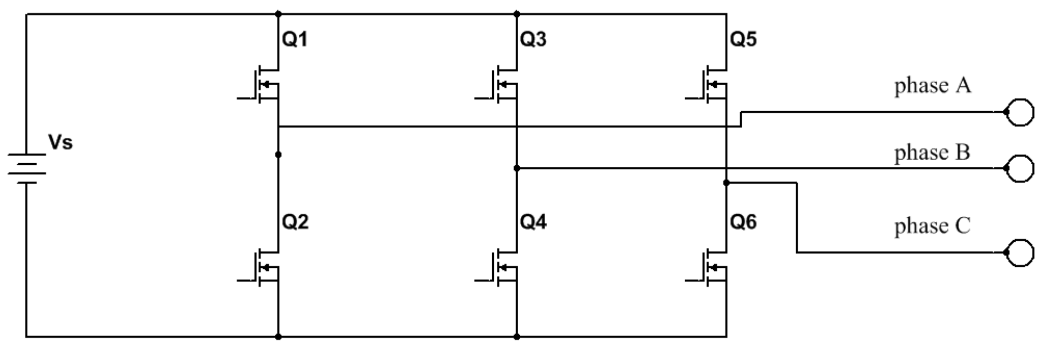

Figure 2.2: Model of APF

There are also switching state for the inverter as shown in Table 2.1. From the switching state, we can see the switches that are connected in series (Q1 and Q4, Q3 and Q6, Q5 and Q2) cannot be turned on at the same time. If the switches on at the same time, there will be short circuit of the voltage supply, Vs.

Table 2.1: Switching state for three phase inverter

State	State No	Switch State	Vab	Vbc	Vca
Q1, Q2, and Q6 are on and Q4, Q5, and Q3 are off	1	100	Vs	0	-Vs
Q2, Q3, and Q1 are on and Q5, Q6, and Q4 are off	2	110	0	Vs	-Vs
Q3, Q4, and Q2 are on and Q6, Q1, and Q5 are off	3	010	-Vs	Vs	0
Q4, Q5, and Q3 are on and Q1, Q2, and Q6 are off	4	011	-Vs	0	Vs

Q5, Q6, and Q4 are on and Q2, Q3, and Q1 are off	5	001	0	-Vs	Vs
Q6, Q1, and Q5 are on and Q3, Q4, and Q2 are off	6	101	Vs	-Vs	0
Q1, Q3, and Q5 are on and Q4, Q6, and Q2 are off	7	111	0	0	0
Q4, Q6, and Q2 are on and Q1, Q3, and Q5 are off	8	000	0	0	0

Then in designing the active power filter, which is the inverter to compensate the current one design is used for APF by using this paper [11] where the APF has been designed for power distribution system as Figure 2.3. This is the general idea of the whole system that can be implemented in this project where there is three phase power supply connected to the nonlinear load, and there is three phase APF to compensate the current distortion in the system.

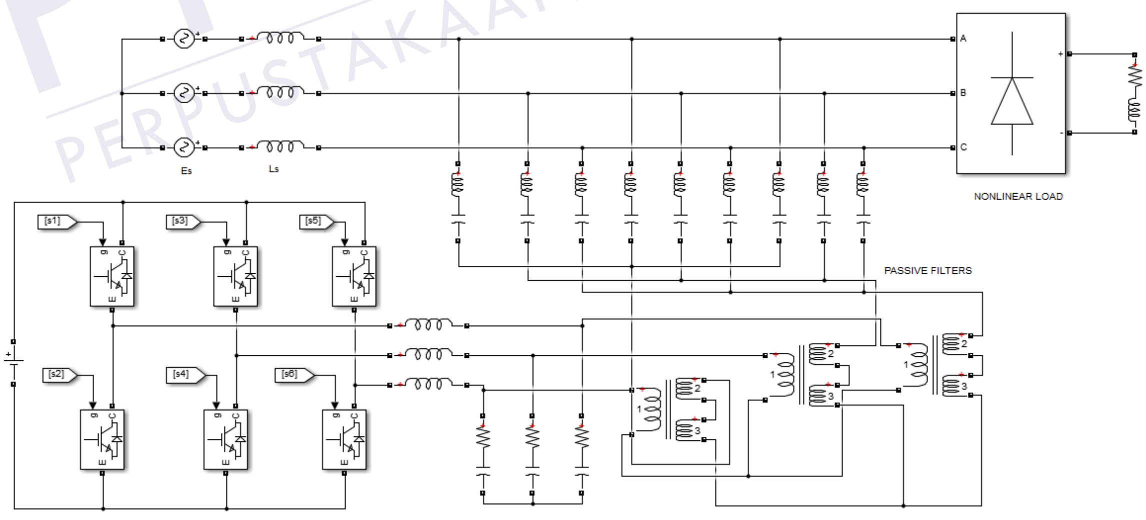

Figure 2.3: Active power filter for power distribution system [11]

Then, there are cases where the output from the APF has a lot of noise and harmonics due to the fast switching from the MOSFET [9][10][12]. So the low pass filter (LPF) must be added to reduce the noise from the APF. The design for LPF varies depends on the APF and the load used. The traditional way of doing this is to calculate and compensate the individual harmonics separately [8][10][13]. Other than this the compensation can be made by modelling the overall APF by using impedance analysis [9]. The impedance analysis is easier if we use single phase power supply, but in this paper, I have been using three phase power supply and the nonlinearity of the load must be in three phase. So the design as in paper [14][15] have been adapted where the LPF is shown in Figure 2.4. From the figure, the LPF that implemented is inductor, capacitor and resistor with common ground. Other than that, there is LPF which consists of inductor and capacitor only [12] where the switching harmonics currents can be removed from the APF by using this method.

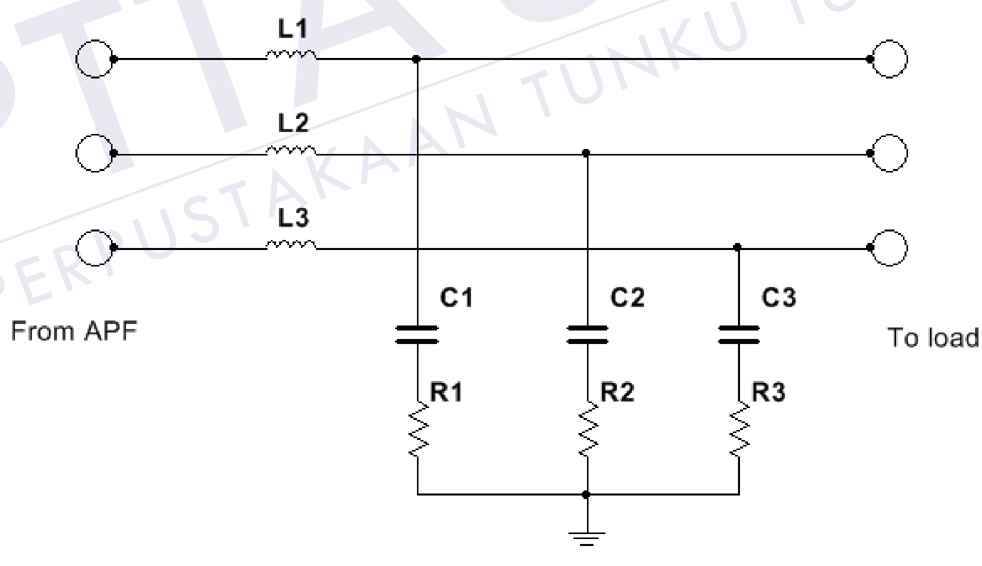

Figure 2.4: Passive Low pass filter

2.3 Controller

Many researches have been done on designing the optimal controller for solving the nonlinear load. There are several controller methods for 3 phase APF such as hysteresis-band PWM current controller, one cycle controller, and lastly the repetitive current controller [1][11][16][17][18][12]. This project will emphasize on repetitive current controller only.

The hysteresis-band PWM current controller used to compensate the harmonics in the circuit research has been done in this paper [12]. In this paper, there are signals from supply voltage which generate three sinusoidal waveforms as reference. Then, there are reference voltage and actual voltage which is used to determine the difference between them. This difference will act as an error and can be compensated by using PI controller. The PI controller will compared the error with the actual voltage to generate current references. The hysteresis-band current controller then is used to generate the pulse for the APF and compensate the current lag.

One cycle current controller has been proposed and researched [1]. This paper is mainly about how to develop one cycle current controller for APF. This paper has two types of unbalanced system which are the unbalanced line voltage and unbalanced nonlinear load. The unbalanced line voltage will still produce the sinusoidal current waveform, but unbalanced nonlinear load will produce the harmonics in line current.

The main focus in this proposal in extended to the repetitive current controller. The principal of repetitive current controller is free time delay can be generated for any periodic time, L [19]. This design is applicable for single in and single out (SISO) where it is called the repetitive system and can be applied to any condition within the period. The generator of periodic signal is represented in Figure 2.5. The design of repetitive control system can be refer to Figure 2.6.

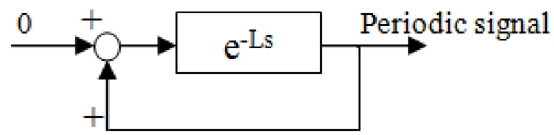

Figure 2.5: Generator of periodic signal

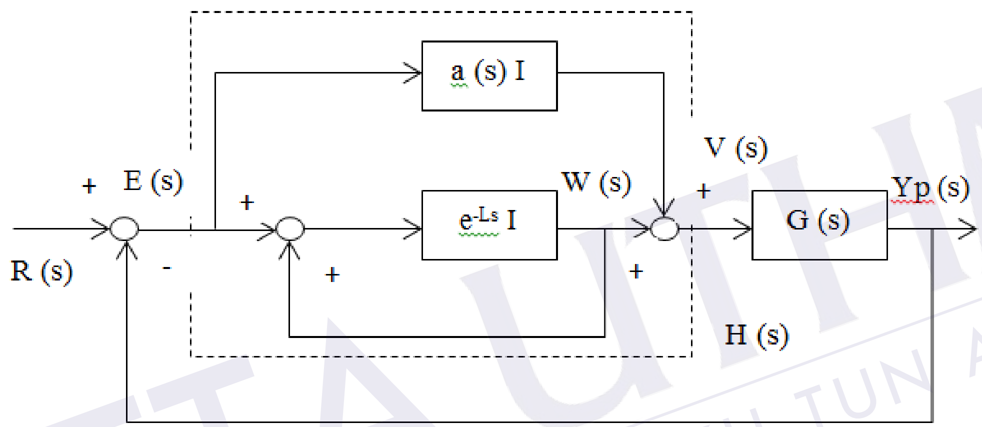

Figure 2.6: Repetitive controller system

Other paper has talked about the precompensator which is the repetitive controller is used to compensate the harmonics [18]. In this paper, it has stressed out that the repetitive controller is the best choice to filter out the resonance in the circuit if the circuit has multiple resonances. If not using repetitive controller, the large amount of filters must be used to compensate the harmonics filter. The repetitive scheme used is feedforward repetitive controller as shown in Figure 2.7.

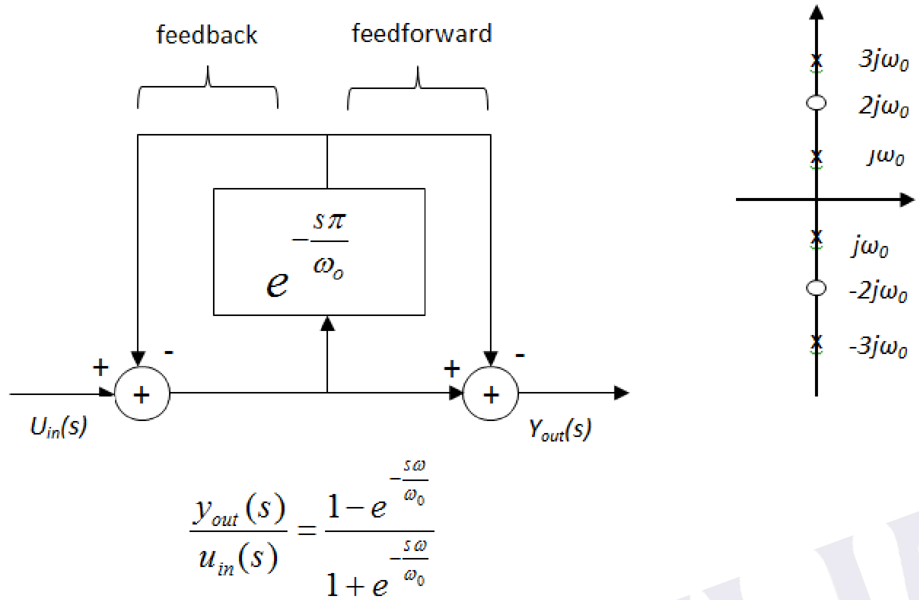

Figure 2.7: Feedforward repetitive controller

There is also paper researched about current control design for active power filter [20]. This paper research is to minimize the steady state zero by the periodic command. The researched done in this paper quite similar with this project, where there is nonlinear load and APF is used for the system. The repetitive current control loop is shown in Figure 2.8. From this paper, the PI is used to eliminate the steady state error. But by having this PI is good if the system is direct current. If the system is ac current, the PI will make the steady state error larger. So the proposed repetitive current controller is to balanced out the circuit and maintains the circuit in sinusoidal waveform.

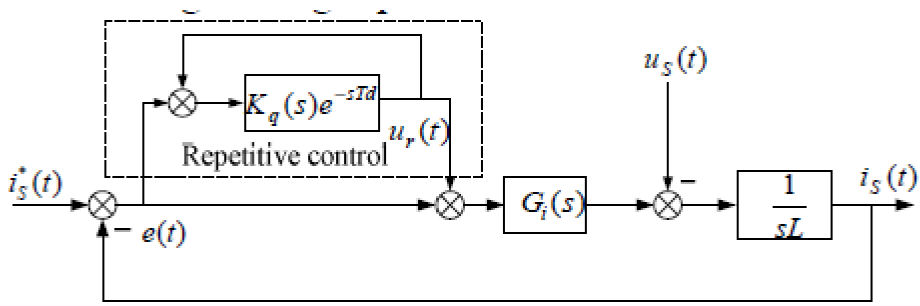

Figure 2.8: Repetitive current controller

2.4 Raspberry Pi

The main focus of running the controller designed is by using Raspberry Pi. This Raspberry Pi has launched its product widely in 2012. It is single-board computer which is only as big as the credit card, developed in United Kingdom by the Raspberry Pi Foundation. Its ultimate purpose in producing this board is as teaching aids in the school for computer science. But this board has stolen much attention from the researchers around the world for its distinguished design and usage, so then it becomes the trend now to develop system by using this Raspberry Pi [21].

The hardware design has evolved since the first released of Raspberry Pi and currently there are two models which are Model A and Model B. The two models had been outlined in Table 2.2.

Table 2.2: Specification of Raspberry Pi

Retrieve from Wikipedia

	Model A	Model B
SoC:	Broadcom BCM2835 (CPU, GPU, DSP, SDRAM, and single USB port)	
CPU:	700 MHz ARM1176JZF-S core	
GPU:	Broadcom VideoCore IV @ 250 MHz OpenGL ES 2.0 (24 GFLOPS) MPEG-2 and VC-1 (with license), 1080p30 h.264/MPEG-4 AVChigh-profile decoder and encoder	
Memory (SDRAM):	256 MB (shared with GPU)	512 MB (shared with GPU)
USB 2.0 ports:	1 (direct from BCM2835 chip)	2 (via the built in integrated 3-port USB hub)
Onboard storage:	SD / MMC / SDIO card slot (3.3 V card power support only)	
Low-level peripherals:	8 × GPIO, UART, I²C bus, SPI bus with two chip selects, I²Saudio +3.3 V, +5 V, ground	
Power ratings:	300 mA (1.5 W)	700 mA (3.5 W)
Power source:	5 V via MicroUSB or GPIO header	
Operating systems:	Arch Linux ARM, Debian GNU/Linux, Gentoo, Fedora, FreeBSD,NetBSD, Plan 9, Inferno, Raspbian OS, RISC OS, Slackware Linux	

The hardware design of Raspberry Pi can be seen in Figure 2.9. The Raspberry Pi has its own processor so it can accelerate the time of processing data. All the peripherals such as the video, audio jack, Ethernet port, SD slot card, CPU, RAM, HDMI and GPIO pins enable the Raspberry Pi to act as a mini computer. So in this design, the repetitive current controller will be designed on this board and it will shoot the PWM to the APF as mentioned before.

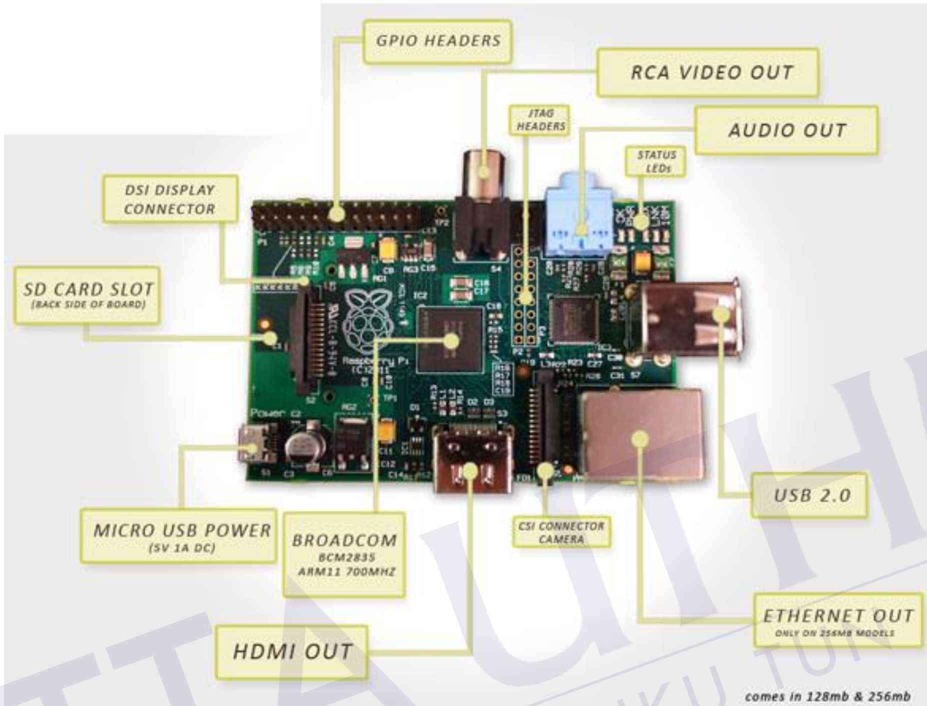

Figure 2.9: Hardware design of Raspberry Pi controller

CHAPTER 3

METHODOLOGY

In this chapter, the methodology of the doing this project has been outlined so that the satisfied results will be acquired. This methodology will include methodological approach in detail, data analysis, and lastly the summarization of this chapter.

3.1 Introduction

In designing the development of repetitive current controller using Raspberry Pi for 3 phase APF for nonlinear load improvement, the most niche area of research is on running the system by using Raspberry Pi. Since the Raspberry Pi has just launched into the market, there are not many papers have been published on this hardware. So the first thing that needed focus is on installing the Raspberry Pi into the Matlab and the integration between them. The flow chart of finishing this project has been outlined as follow:

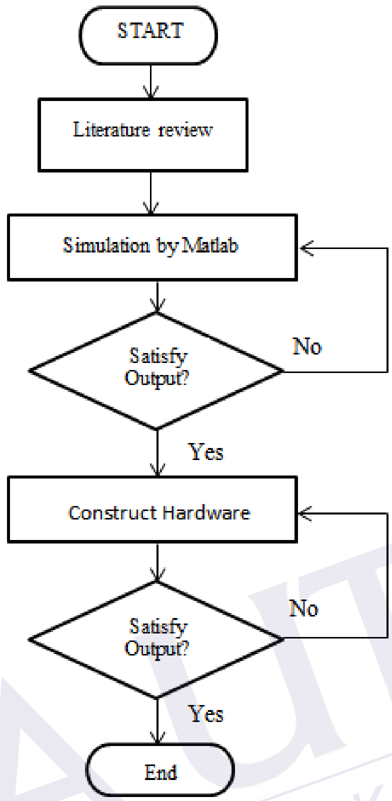

Figure 3.1: Flowchart on project

The whole system in the development of repetitive current controller using Raspberry Pi for 3 phase active power filter (APF) for nonlinear load improvement can be cleared out by referring to the block diagram in Figure 3.2. The three phase ac source will connected to the nonlinear load. Then there are current sensors tapped at each line to detect the distortion of each line. After the sensor detected the distortion current in the ac line current, the repetitive current controller will inject back and compensate the current through the APF, which is three phase inverter. This controller comes from the Raspberry Pi and the output of the Raspberry Pi must go through the gate driver before it connected to the APF.

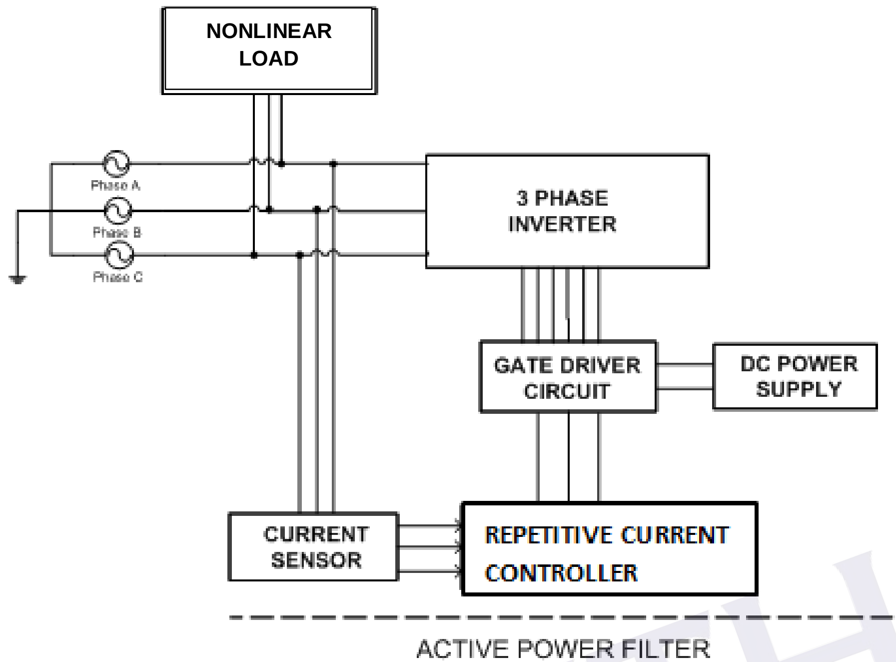

Figure 3.2: Block diagram of the project

After the project has been sure to finalize, this project has been started by developing the three phase power supply from the main source. In this stage, step-down transformer is used to step down the voltage source from 240V to 24V as shown in Figure 3.3. The important thing to do this type of wiring is to make sure the safety by using fuse and the grounding to avoid electric shock.

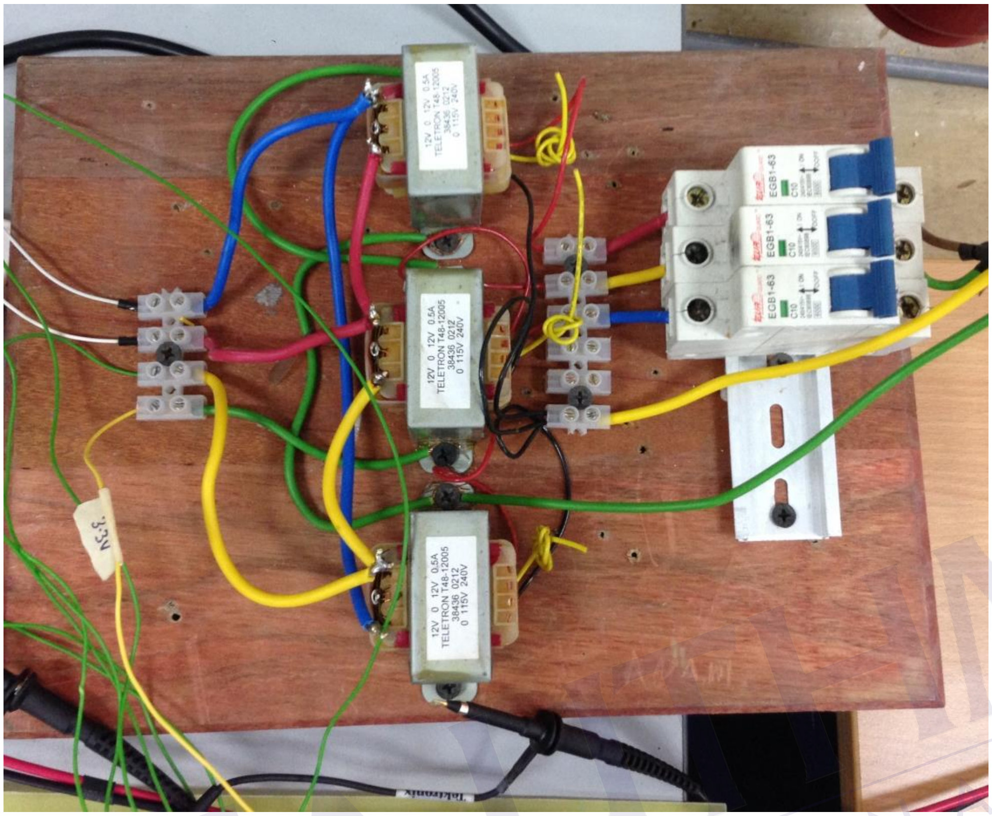

Figure 3.3: Three phase power supply

3.2 Nonlinear load design

The project has been preceded into designing the system by using Simulink. The linear load has been simulated before the nonlinear load as shown in Figure 3.4.

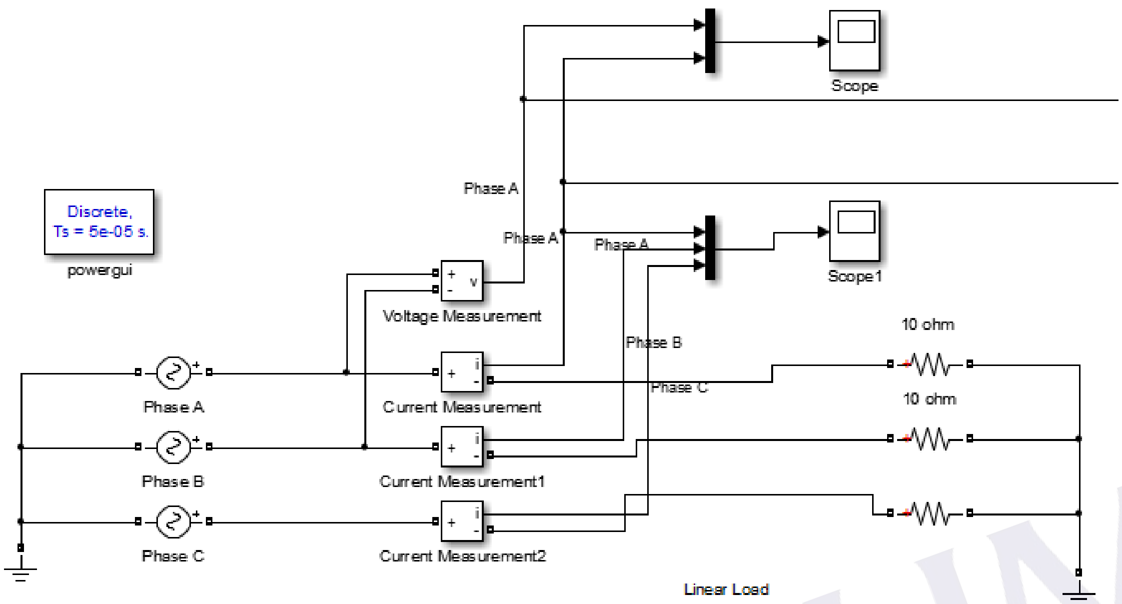

Figure 3.4: Linear load design

Then, the nonlinear load is designed as shown in Figure 3.5 which is the rectifier connected to R load. The value of R is same with the linear load design which is 10Ω. This passive components and the bridge rectifier will produce the double hump current waveform instead of pure sine wave. The universal bridge used is three phase rectifier as shown in Figure 3.6.

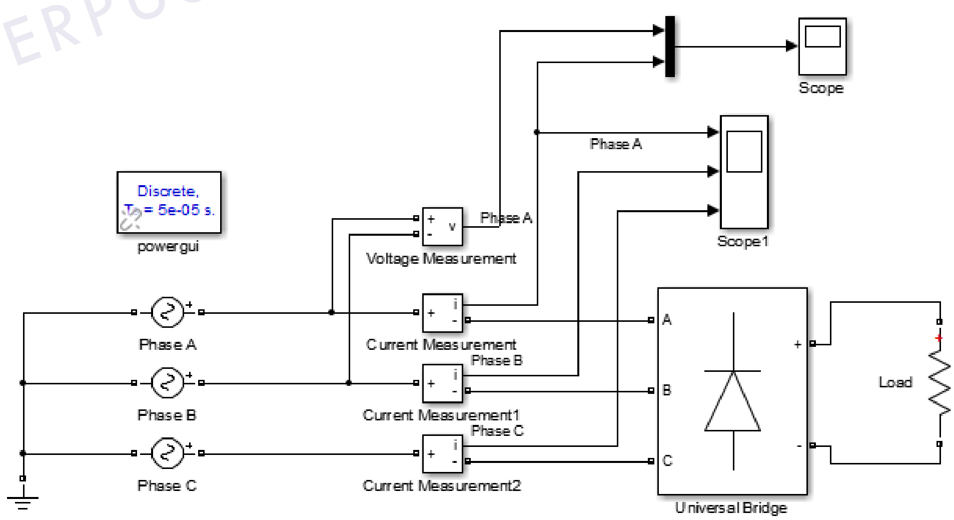

Figure 3.5: Nonlinear load design

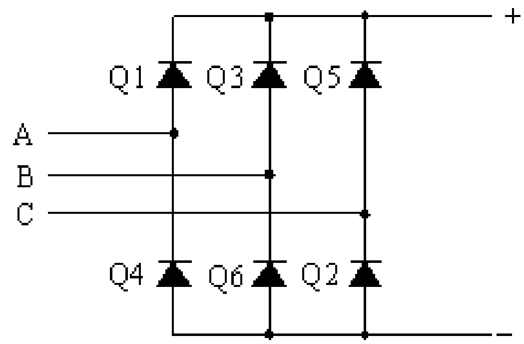

Figure 3.6: Universal bridge rectifier

After designing, the nonlinear load has been fabricated as shown in Figure 3.7. The bridge rectifier by using diode and a 10 ohm resistor has been soldered into the Printed Circuit Board (PCB) board.

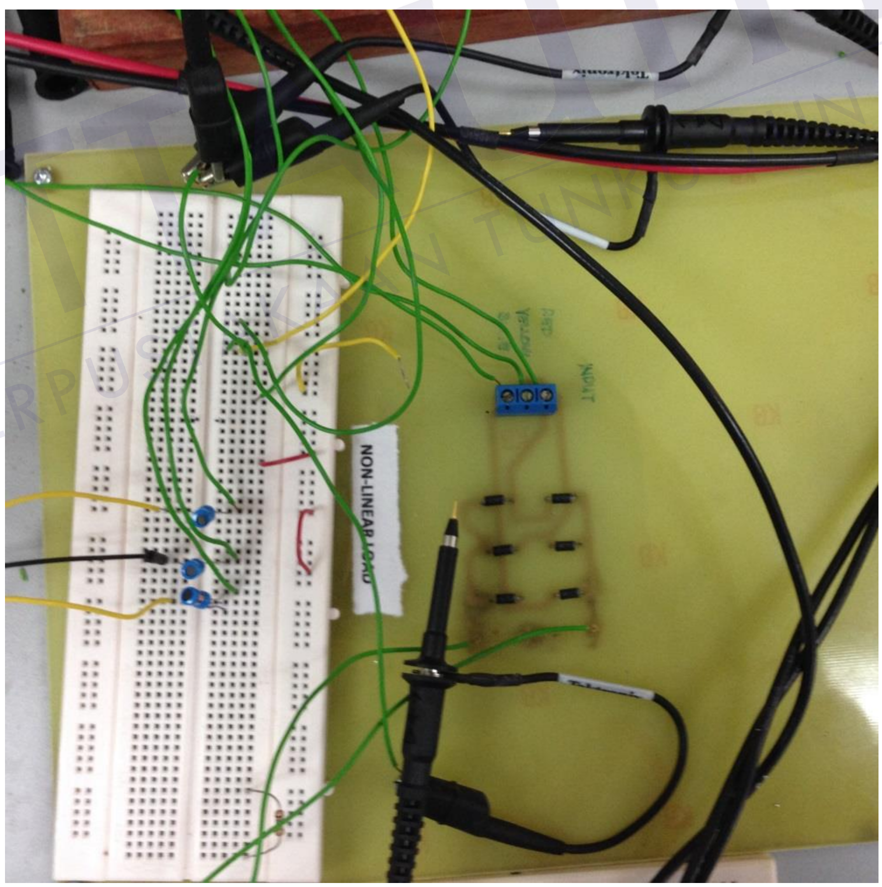

Figure 3.7: Hardware of Nonlinear load

3.3 3 phase APF design

The three phase APF is used to compensate the current in the system. The APF is consists of inverter, which convert DC voltage to AC voltage as shown in Figure 3.8. In this design, the switch used is Insulated Gate Bipolar Transistor (IGBT) and the signal pulse to run this inverter is obtained by the PWM. In this design, IGBT is the best choice over MOSFET because the MOSFET is a voltage control device and a low power capability but fast switching speed, while IGBT has medium power capability and medium switching speed [22].

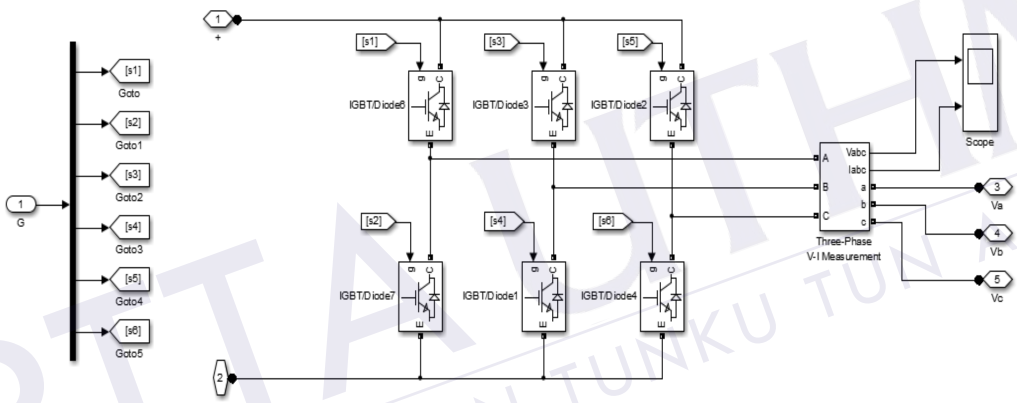

Figure 3.8: Three phase APF design

After several researches, MOSFET is used instead of IGBT for the hardware because MOSFET is good enough for faster switching speed, and there is no apparent distinction between MOSFET and IGBT. The hardware has been designed and fabricated by using double sided PCB as in Figure 3.9. In each MOSFET, there is heat sink needed because of faster switching of frequency 5000Hz, the MOSFET can become too hot.

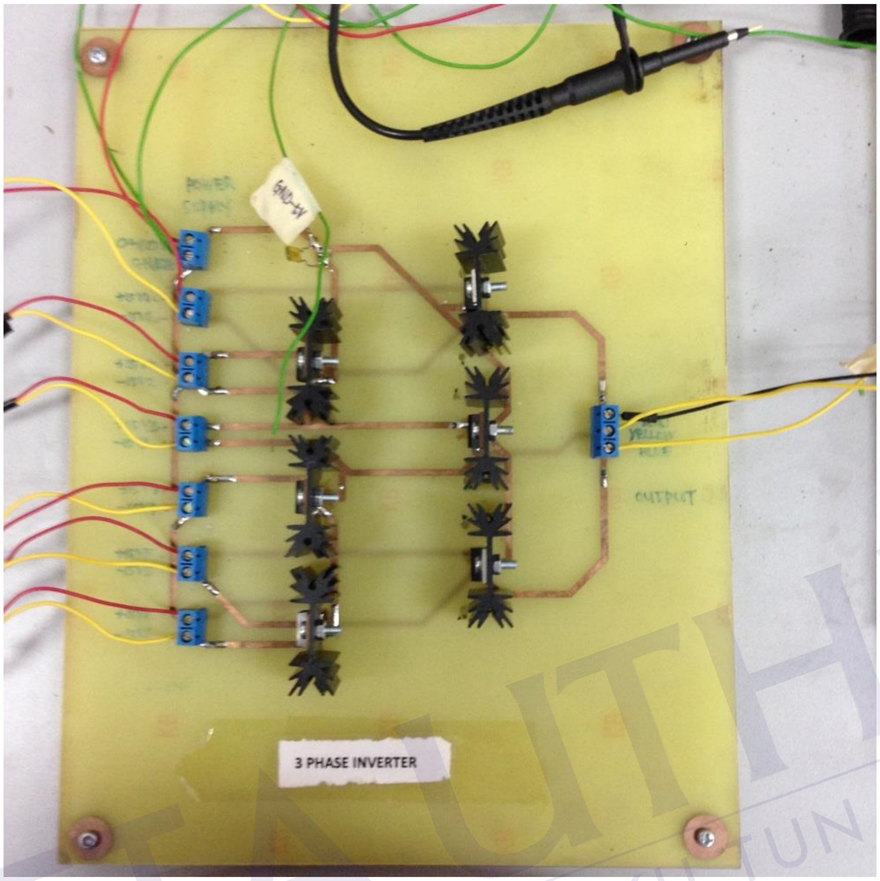

Figure 3.9: Hardware of three phase APF

3.4 Gate driver

The gate driver is important in order to amplify the output voltage from the Raspberry Pi to the APF as well as for isolation circuit.

Figure 3.10 shows the schematic diagram that will develop for the gate driver by using Proteus Professional 8 software. The Raspberry Pi will generate 3 PWM input to the gate driver. Then the gate driver will divide the signal into two opposite signal with each other and inject it to the MOSFET in the APF. One signal will supply to the Hex SChmit-Trigger Inverter and one signal will supply to the NOT gate (IC7414) and zener diode. This step is important because the feedback current can flow back to the

Raspberry Pi and damage the board. Other than that, the series switch in the inverter cannot turn on at the same time because it will short the voltage supply.

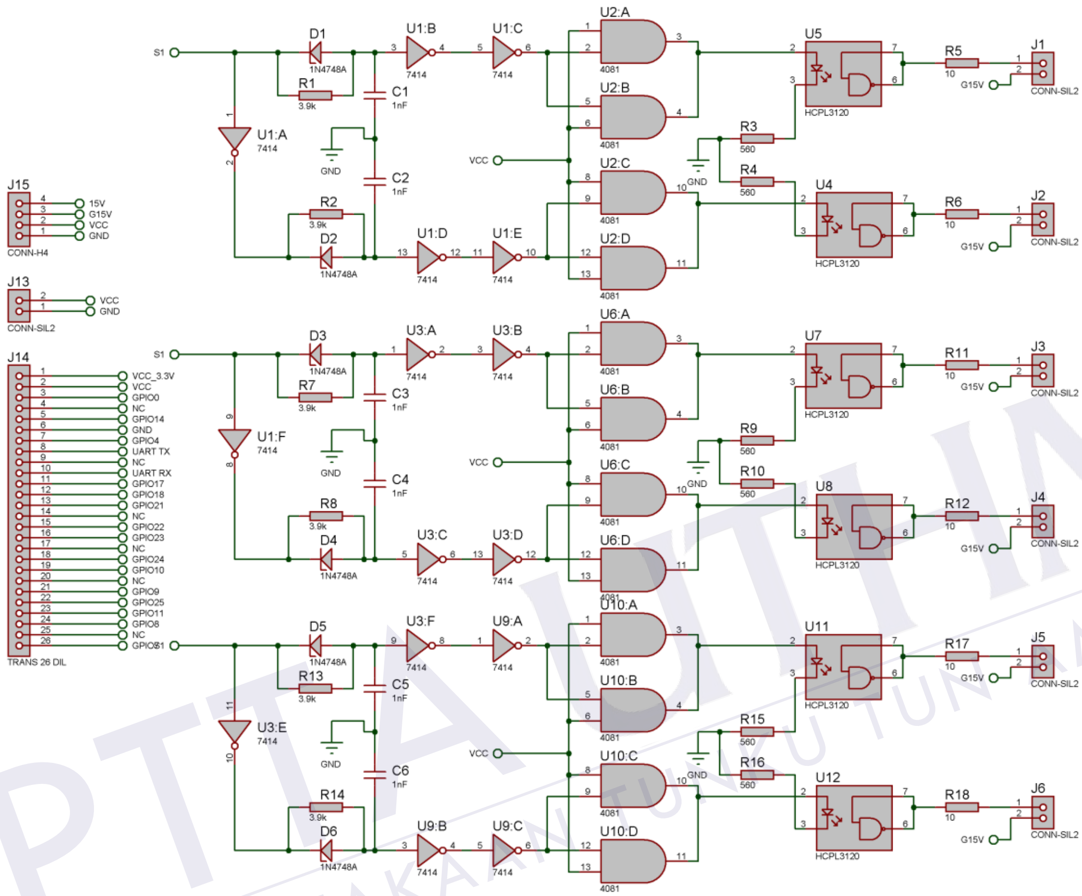

Figure 3.10: Schematic Diagram of the gate driver circuit

The PWM signal will amplify through NOT gate IC 7414 and Quad 2 input AND gate IC 4081. Then the amplified signal has been supplied to the optocoupler HCPL3120 which has gasp LED optically coupled to an integrated circuit with a power output stage. The optocoupler will have minimum supply voltage of 15V. The hardware of the gate driver with three inputs and six outputs is shown in Figure 3.11.

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